An Open-Source, Low-Cost Apparatus for Conductivity Measurements Based on Arduino and Coupled to a Handmade Cell

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The device circuit

As said in the main article, Arduino easily produces 5 and 3.3 continue voltage (DC) and pulses from 0 to 5V at intervals from few milliseconds up to some minutes; it also produces pulse signals with modulation (PWM) with frequency about 500 and 1000 Hz with a duty cycle up to 256 levels but, anyway, the signal is a square wave between 0 and 5 V. Unfortunately, a symmetric voltage centered on zero (as an example –1.5, 0, +1.5V) cannot be instead produced.
Following the description in original article in order to obtain a continue inversion of polarity between electrodes, an external shield/circuit is usually needed, Fig AA shows the one we propose

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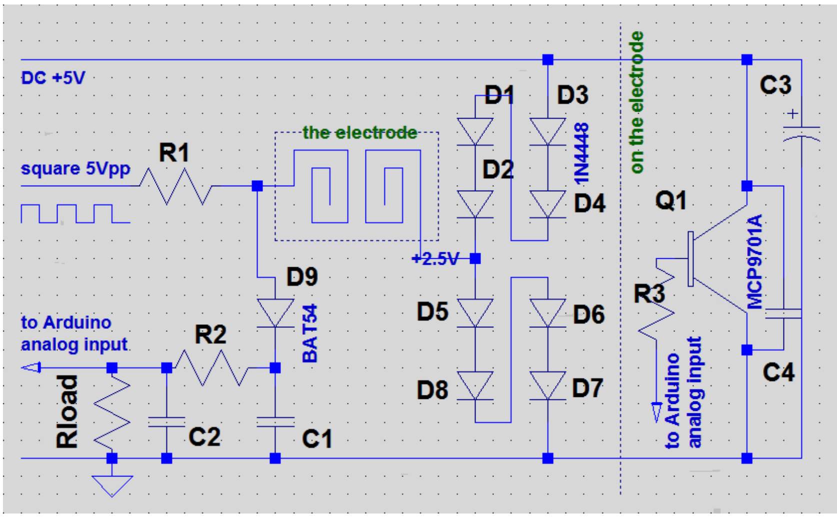

Fig.AA; the complete schematics of the proposed instrument with the shield board on the left and the electrode board on the right. Each component is described in the text

Reading the circuit schematically we can see:
a) the series of diode D1-D8 that is used to produce a center-tap at 2.5V directly connected to one of the electrodes to be immerged in solution. The silicon diode 1N4448 was used in place of common 1N4148 for its lower forward voltage (a possible substitute is only the 1N914b).
b) the signal coming out from Arduino with 50% duty cycle for PWM (setting value equal to 127) at frequency of about 1 kHz, let to obtain an almost perfect square-wave, see Fig.4

c) The R1 resistor, acting as current limiter, is directly connected to one of the electrodes, so the voltage applied on it spans from 0 to +5 V against the +2.5 V fixed on the other electrode; so, a voltage swing between ± 2.5 V can be obtained. Having 2.6 V peak to peak the true RMS value is about 880mV comparable to that of a commercial instrument.
d) the different resistance (conductivity) of the solution under measure produce a different voltage drop between electrodes, the diode D9 and capacitor C1 acting as a simple rectifier to measure this voltage.
e) the R2 resistor and C2 capacitor constitute a low-pass filter to reduce the noise produced by the stirring of the solution, the noise in the 5Vdc, wires, e.g., the noise cannot be completely suppressed to permit the oversampling used by software to enlarge the resolution of Arduino ADC. In SM is shown a screenshot of a value measured by Arduino without R2-C2, with 1 bit oversampling, file *Fig-S4_noise-shoot-in-air.png*.
f) the resistor Rload is "the load" of R2-C2 circuit and also the load of D9-C1 circuit, changing this value the sensitivity of apparatus can be set
g) on the electrode board there are, of course, the 2 spirals of stainless steel, with diameter from 130 mm to 80 mm, according to the conductivity range to be measured.
h) Many temperature sensors can be used with Arduino, such as Thermocouple, PT1000, NTC, PT100, PTC, but accurate values can easily be obtained with an integrated circuit (IC) dedicated only to temperature measurement. Often the old LM35 was used, while in our case the modern MCP9701A was chosen (Q1 of Fig.AA) because it has twice the sensitivity of the old one (19.5 mV/°C). The resistor R3 acts as an impedance coupler for shielded wire (see details in SM), the last are needed when the measure circuit is far from the conductivity cell, just as an example for measure in a well. R3, C3 and C4 were suggested by IC datasheet for stability.
i) the full sensitivity of the IC can be exploited by using some tips and tricks in the software. We run routines to separate the processes devoted to the temperature measure: we change on fly, the voltage reference of Arduino ADC to 1.1V (internal), measure the IC voltage, reset to 5V and return, to permit the measure of electrodes.
j) the software used to program Arduino is IDE Release 1.8.9. The sketch (file *Conduct-temp1.2.ino* present in SM), is written by scratch, without library or reusing another module. The sketch was split in part with large use of routines and subroutines to obtain an easy-to-read listing and more reliable object, the main routine is devoted to oversampling-and-decimation for temperature and conductivity measure.
k) the values of temperature and conductivity come out from Arduino through its USB port. The software produces a "line" in the output every 5 second (setting inside the sketch) with the values in bits from the internal converter (up to 2048 for temp. and up to 4096 for conductivity); the table can be saved for future analysis. In SM there is an example of output in file *in-Air-and-Tap-Water.txt*
l) we like to present the instrument as an Open-Source project so in SM a long text entitled "how to build it" is available, describing step by step the acquiring of components, the soldering, the cable and wires to be used, the installation of the software sketch, some measures to check the obtained circuit (file *How-to-build-it-R2.doc* in SM). We used the Copyright under the terms of the GNU General Public License as published by the Free Software Foundation; both version 4 of the following License "Creative Commons Public License, CC-BY-NC-ND 4.0 EN" [37]. More, the schematics and drawing of the shield and electrodes-temperature module are under same license.

The file *Fig-S5_the-shield-with-letter.jpg* in SM shows the photo of the shield while file *Fig-S6_the-electrodes-with-letter.jpg* shows the 2 sides of the electrode board.